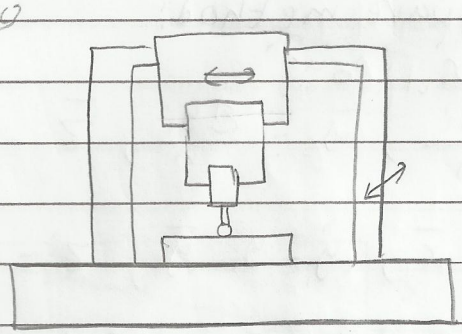
5- Out of flatness

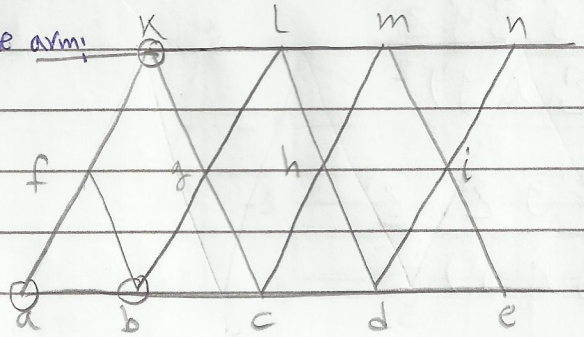
* Flatness error: It is the depature of the surface from a true flat plan
- Out of flatness: It is the min. distane between 2 plans containing all the irregularities of the tested surface

* Experimental procedure:
- The entire surface is divided into a series of imaginary straight lines form a grid and the variations in heights of points of intersections of lines are determined experimentally relative to some datum plane
- The experimental readings are then modified to become relative to the true mean plan

* Experimental techniques:
1- Using CMM: For small sizes



2- Using Rotatable arm:



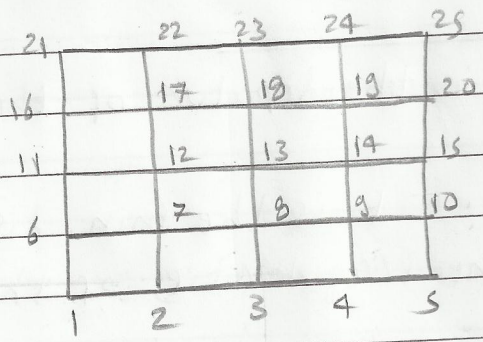
Position

abc
bcd
cde
afK
cgK
fgh
ghi
bgl
Klm
lmn

Position	Reading	1st	Middle	last	Height	Point wise
	Z	P	q	r	r = Z+eq-P	
abc	5	0	0	2	r = 5+0+0	c 5
afK	-3	0	→	0	3+2+4	f 11.5
			↑			
			- or 0			

Subject. Date.

3- Using sensitive level



x_i	y_i	Reading FWD	Reading BWD	Reading Average	Accumulated Degree	Accumulated mm

* Out of flatness calculations;

1- Least square method:

$z_i = a x_i + b y_i$

$\bar{x} = \frac{\Sigma x_i}{n}$, $\bar{y} = \frac{\Sigma y_i}{n}$, $\bar{z} = \frac{\Sigma z_i}{n}$

$x'_i = x_i - \bar{x}$, $y'_i = y_i - \bar{y}$, $z'_i = z_i - \bar{z}$

$$a = \frac{\Sigma y'^2 \Sigma x'z' - \Sigma x'y' \Sigma y'z'}{\Sigma x'^2 \Sigma y'^2 - (\Sigma x'y')^2}$$

$$b = \frac{\Sigma x'^2 \Sigma y'z' - \Sigma x'y' \Sigma x'z'}{\Sigma x'^2 \Sigma y'^2 - (\Sigma x'y')^2}$$

Out of flatness = $z_i - \hat{z}_i$

Exp.

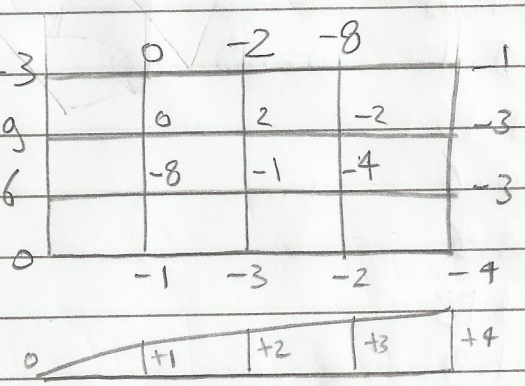
x_i	y_i	z_i	x'_i	y'_i	z'_i	$x'z'$	$y'z'$	x'^2	y'^2
$\bar{x}$	$\bar{y}$	$\bar{z}$							

2- Semi-analytical;

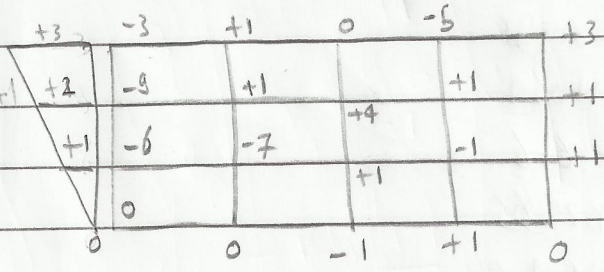
- Rotate the points about lines, till they are symmetic about a line

Example;

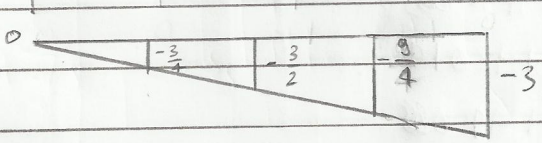
Rotate about (0,-3) line to make (9,-4) line horizontal

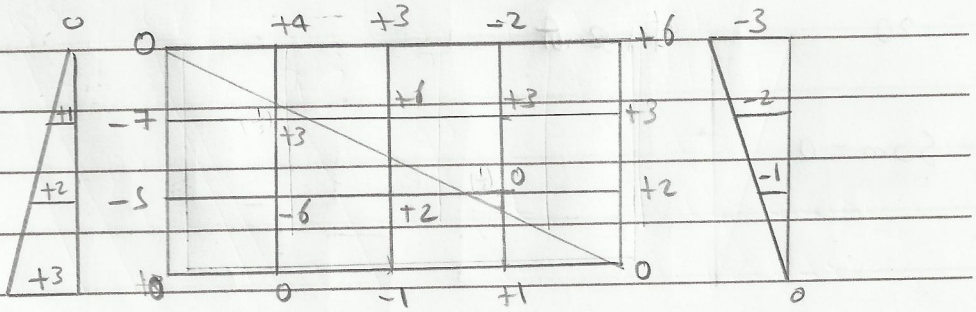


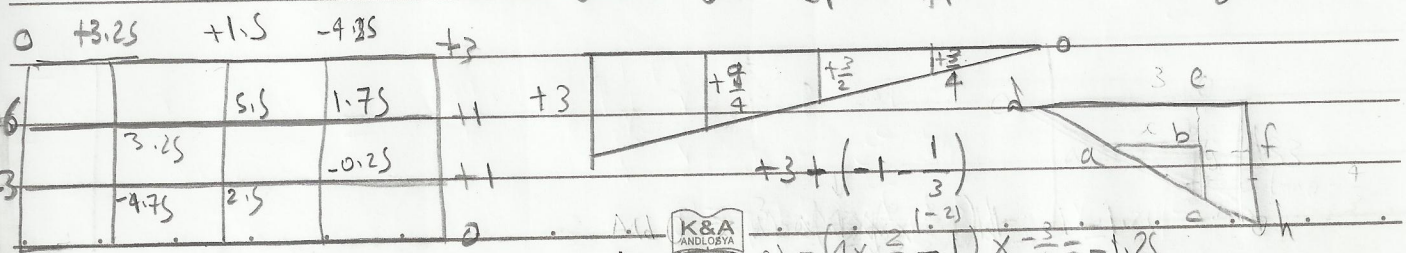
Rotate about (0,0) line to make (0,-3) line horizontal



Rotate about diagonal (0,0) to make the plane symmetric about a plan (up=down)







Δ afh $\Rightarrow$ $ab = \left(4 \times \frac{2}{3} - 1\right) \times \frac{-3}{4} = -1.25$

Δ cde $\Rightarrow$ $bc = (3 \times \frac{3}{4} - 1) \times \frac{-2}{1} = -1.25$

Sum = 12 ≠ 0 ⇒ subtract from each (c) ; $c = \frac{12}{20} = 0.6$

Point	Height (mm)
1	+2.4
2	+1.65
3	-0.1
4	+1.15
5	-0.6
6	-3.6
7	-5.35
8	1.9
9	-0.85
10	+0.4
11	-6.6
12	+2.65
13	+4.9
14	+1.15
15	+0.4
16	-0.6
17	+2.65
18	+0.9
19	+4.85
20	+2.4

Sum = 0